Development of a Low-Cost UAV Doppler Radar Data System

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Scope of Discussion

- Science Mission of Radar

- Radar RF Design

- **Radar Data System Design**

- Results

Science & Mission Background

- Evolution processes of tropical cyclones are still poorly understood.

- Need for tropospheric and surface wind measurements with higher spatial resolution than currently provided.

- Necessity to develop a low cost X-band radar that will fly on **high altitude, long endurance UAVs**, such as Global Hawk as cyclogenesis occurs over areas inaccessible to piloted aircraft.
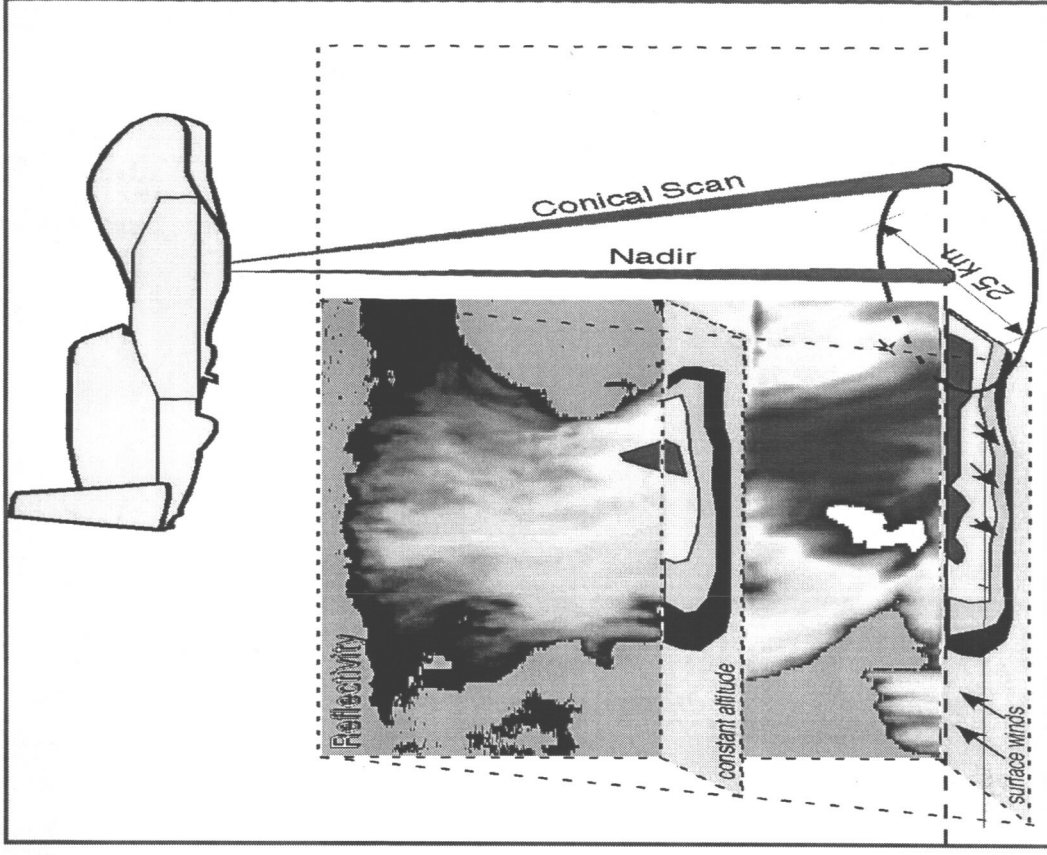
Science & Mission Background

➢ The planned radar/scatterometer will have capabilities of the ER-2 Doppler Radar (EDOP).

➢ Conical beam for ocean surface winds and surveillance of the precipitation regions of the storm.

➢ Nadir beam for vertical winds and precipitation structure. **This talk focuses on the nadir system only.**
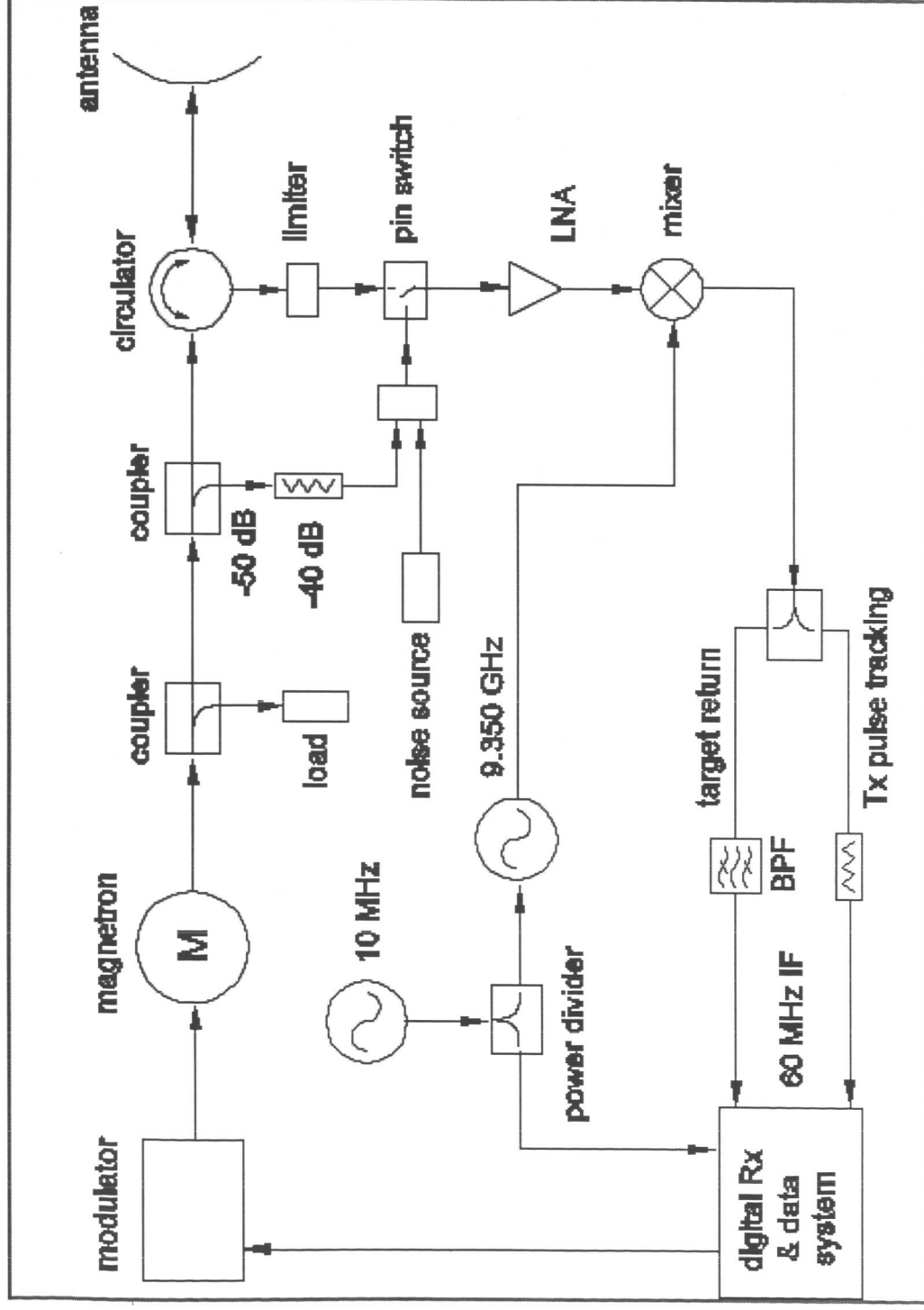
Radar Requirements & Specs

- 9.41GHz X-Band Radar
- 2.5KHz -2.0KHz adjustable PRF and Pulse Width
- Pulse-Pair Doppler Retrieval
- Low Pressure Environment
- Low Heat Production
- **Low Cost A Primary Design Influence**

Radar Realization: RF System

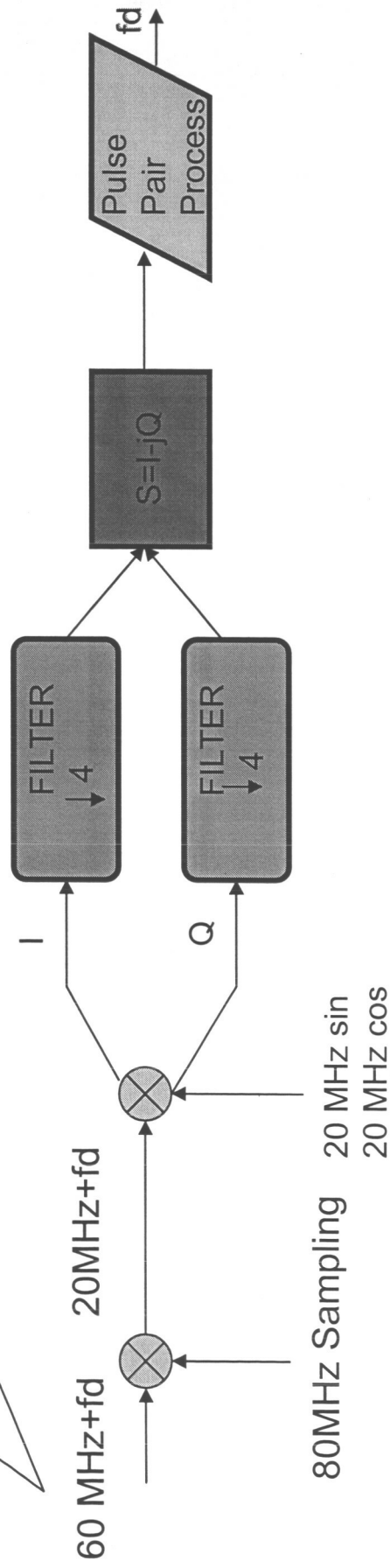- Cost Saver: Modified Marine Radar - Furuno Model FR-1510
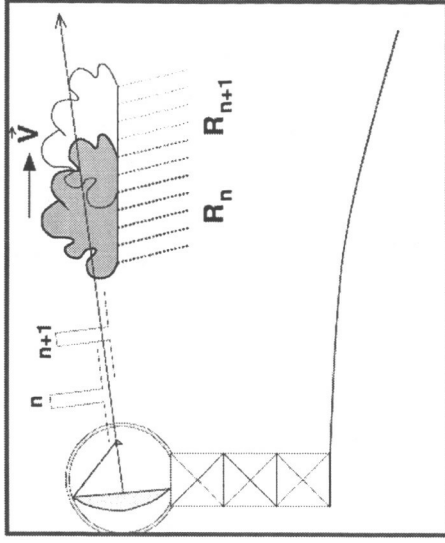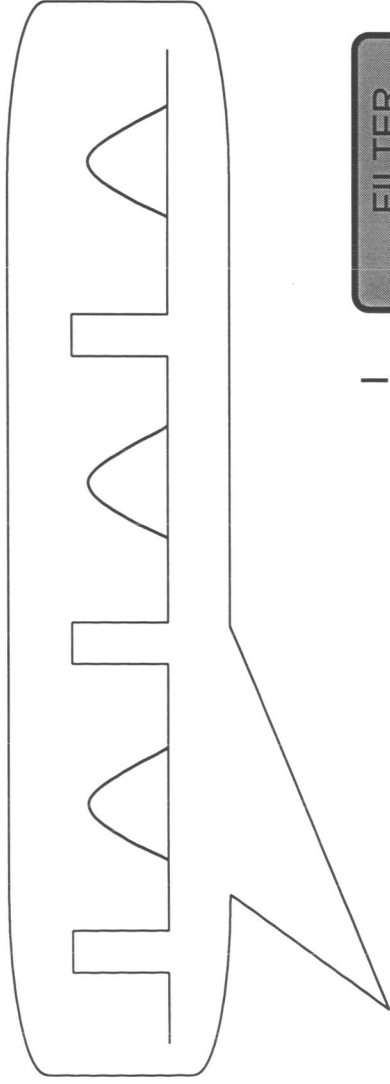
Processing of RF Signal
RECEIVER PROCESS ON MATLAB

AT RECEIVER:

60 MHz+fd

20MHz+fd

80MHz Sampling   20 MHz sin
20 MHz cos

I

Q

FILTER ↓4

FILTER ↓4

S=I-jQ

Pulse Pair Process

fd

R_n R_{n+1}

$\vec{V}$

n   n+1

Data System Design Process

- ## Requirements

  - Sample IF Data (60MHz + fd)

  - Perform Pulse-Pair Doppler Retrieval

  - Record Data Along With Time & Navigation Info

  - Monitor Radar System and Respond to "Pilot" Commands

  - Operate Within Global Hawk Thermal & Pressure Environment

  - Periodically Correct NCO's to Compensate for Magnetron Drift

- ## Approaches For Cost Savings

  - Use Single Intel-Based Computer

  - Use COTS Hardware Where Possible

  - Use Linux (Free)

  - Write Our Own Software

  - **Remove Expensive Custom DSP For Processing, Use Main CPU Instead**

Can We Remove the DSP?

- To remove the DSP and save cost, the computer system must be fast enough to acquire, process and store the data while running the larger radar system. I hypothesize that typical modern PC architecture is fast enough to do this. But how do you determine beforehand if the computer can accomplish this?

Determining Approximate Speed Requirements

- **Step 1:** Determine How Fast Data Flows to Reciever Card FIFOs and time to fill the FIFO

- **Step 2:** Determine How Fast You Can Move Data From FIFOs, across PCI bus and into System Memory

- **Step 3:** Calculate the number of operations needed to process a set of data

- **Step 4:** Find minimum processing speed to perform all operations faster than the time it takes to fill the FIFO less the time to move FIFO data to memory less time to move data into the CPU.

Determining Approximate Speed Requirements

Step 1: Determine How Fast Data Flows to Reciever Card FIFOs and time to fill the FIFO

- To meet science requirements, we require 720 32bit I & Q samples per period of the 5KHz PRF = 7.2MBytes/S into FIFO.

- Selected reciever card has 4x32KB FIFO, 2x32KB effective with double buffering.

- 2048x32B / 7.2MB/S = 0.28mS to fill FIFO. (T_{fifo})

Determining Approximate Speed Requirements

Step 2: Determine How Fast You Can Move Data From FIFOs, across PCI bus into System RAM then into CPU registers. This represents a **worst-case** timing scenario.

- PCI DMA transfer operating at 33MB/s, FIFO moved to system RAM in 2KB / 33MB/s = 0.62uS (T_{read}).
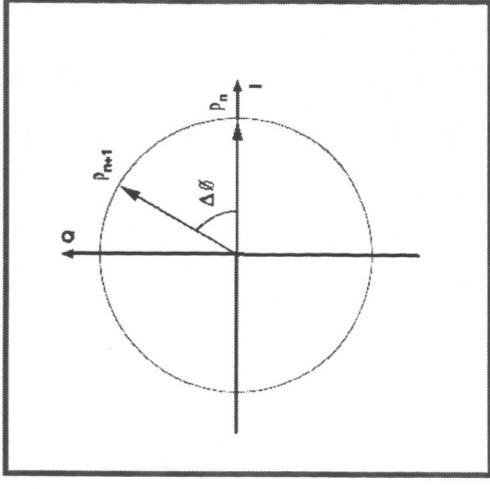
Determining Approximate Speed Requirements

PULSE PAIR ALGORITHM

- Two consecutive pulses

$P_1 = Real_1 + Imag_1$

$P_2 = Real_2 + Imag_2$

$$f_d = \frac{\partial \phi}{\partial t} = \frac{1}{2\pi T_s} a\tan\left(\frac{Im(P_1 * \times P_2)}{Re(P_1 * \times P_2)}\right) = \frac{2v_d}{\lambda}$$

Sequence of M uniformly spaced pulses:

$$R(T_s) = \frac{1}{M}\sum_{n=1}^{M-1} P*(n) \times P(n+1)$$

$$\phi = a\tan\left(\frac{Im(R(T_s))}{Re(R(T_s))}\right)$$

$$f_d = \frac{\phi}{2\pi T_s}$$

Determining Approximate Speed Requirements

Step 3: Calculate the number of operations needed to process a set of data

- In pulse pair processing, the complex return signal is correlated with itself and two following pulses. This "set" from three correlations is then added to the correlation results of the next "set" of three and so on.

- Hence (8 multiplies + 3 adds)*720Samples/Pulse = 7,920 operations/correlation.

- 3 correlations/set * 7,920 operations/correlation + (6 adds*720samples) = 28,080 operations/set.

- Note: Each set is 720samples/pulse * 2 I&Q * 3 pulses/set = 4,320Bytes/set. So two FIFO reads are required to have enough data to process a complete set.

Determining Approximate Speed Requirements

Step 4: Find minimum processing speed to perform all operations faster than the time it takes to fill the FIFO less the time to move FIFO data to memory less the time to move the set data into the processor.

- Now move data from RAM to processor registers. A 400MHz FSB may take 5 clock ticks to do this. So $T_{ram-to-CPU}$ will be 4,320Bytes/set * 5ticks/read / 400MHz = 54uS ($T_{ram-to-CPU}$)

- $T_{fifo} > T_{process} + T_{read} + 2*T_{ram-to-CPU}$, so $T_{process} < 0.17mS/set$

- Minimum operations/second = 28,080 operations/set / 0.17mS/set

- Minimum operations/second = 164Moperations/S

- Minimum CPU Clock = 164Moperations/S * 4 ticks/Operation = 656MHz

- **We are within an order of magnitude of current commercial PC speeds.**

Radar Realization: Data System

- PMC chassis and motherboard reduce size and are designed for low-pressure.

- Intel Pentium-M @1.6GHz reduces heat & meets speed requirements

- Echotech GC314-PMC-FS reciever card records data

- Standard I/O card controls radar

- Ethernet communicates with UAV "Pilot"

- Pressurized commercial hard drive

Data System Operation

- Highest Priority Given to Acquisition and Processing of Data. All other system functions performed when data processing is complete and no DMA transfers are occuring with receiver card.

- Other functions include
  - Monitoring Radar Housekeeping Information
  - Monitoring Commands from the "Pilot" via ethernet
  - Collecting Navigation Info
  - Writing Data to Disk

- Every few minutes, data collection is paused, and high-speed FFT's are taken of the transmitted signal to see if magnetron frequency has drifted. If it has, receiver card NCO's are adjusted to compensate and normal data collection resumes.

Results

- System is operational, atmospheric profiles attained. (Figure TBD)

- Cost of DSP and TMT transmitter removed from development without impacting science quality.

- DSP elimination calculation generic & useful for all radar techniques.

- Lesson Learned: Purchase high-speed data collection software.

IGARSS 2005

25th Anniversary

IGARSS 2005

25~29 July 2005 Seoul, Korea

"Harmony between Man & Nature"

International Geoscience and Remote Sensing Symposium

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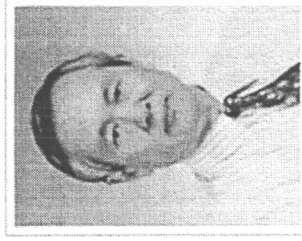- Travel Support
- Visa Information
- Hotel Reservation
- Contacts

Hi Seoul Seoul Metropolitan Government

IGARSS'05 1st Circular

Welcome Message

GREETINGS FROM GENERAL CHAIRMAN

On behalf of the IGARSS 05 Local Organizing Committee, I would like to invite you to experience Korea in its unique setting. Our planet Earth is changing through explosive population growth and accelerating industrialization, particularly in East Asia, to ensure economic growth, social welfare, more leisure and better transportation. Researchers and world leaders now recognize the serious environmental problems associated with achieving these aims and have started to discuss the responsibilities associated with "environmental stewardship".

The members of IEEE Geoscience and Remote Sensing Society (IEEE GRSS) have played an active role in scientific and technological leadership in this respect. IGARSS is a natural forum to continue this discussion as we explore the conference theme, "Harmony between Man & Nature". When we look back, IGARSS has accomplished remarkable growth during the past twenty-five years and the IGARSS in Seoul, Korea, will be the 25th anniversary symposium. We are planning to celebrate with a series of events including the participation of past presidents of IEEE GRSS and many distinguished leaders in our field. I encourage all who have an interest in remote sensing, Earth observation, instrumentation, global change and spatial information science and engineering to join us in marking this milestone.

The return of IGARSS to Asia, after Tokyo and Singapore, is timely for many reasons. East Asia is the most rapidly growing industrial society in this century, both in terms of population and in industrial capacity, and the membership of IEEE GRSS is also expected to grow the
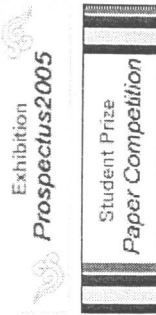
most rapidly in this region. Korea has been known in East Asia as the "Hermit Kingdom of Morning Calm", throughout most of the five thousand years of its history. It has certainly changed and you will experience beautiful natural environment, the mountains and streams, along with one of the world's most dynamic lifestyles. A visit to Seoul and other parts of Korea will reveal many historical and cultural gems, such as palaces, museums, theatres, and temples, for you and your family. Korea is also planning to launch a new Earth observation satellite KOMPSAT-2 with 1-m resolution in 2005, one of many new satellite programs.

A long time ago, the Greek poet, Euripides (c. 485–406 BC) wrote a very short poem:

The whole wide ether is the eagle's way:
The whole Earth is a brave man's fatherland.

Travel through your fatherland and join me in experiencing IGARSS in wonderful Seoul, Korea.

Sincerely,

Prof. Wooil Moon
General Chairman. IGARSS 05

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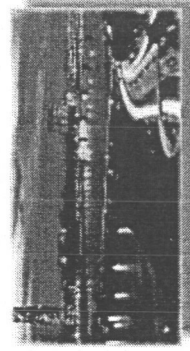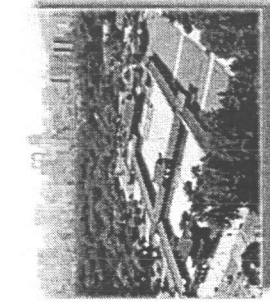- Travel Support
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Hi Seoul Seoul Metropolitan Government

IGARSS'05
1st Circular

▦ General information

● **Seoul, Korea,**

..... ¡°See its Beauty Old and New¡±

Seoul is one of the world¡¯s most fascinating cities located at the foot of Han River. A unique Confucianism and Buddhism heritage flourished over 6 centuries offering to visitors a distinct charm of Oriental traditions. Seoul is also the capital of the Republic of Korea with residents numbering well over 13 millions, occupying about a quarter of the total population of Korea. All the main stream of politico-economical and cultural activities runs into and out of Seoul, which makes it a very colorful city encompassing a variety of elements.

Seoul is a metropolis where rivers and cultures come together. Palaces in the center of downtown Seoul provide an opportunity to relive great moments in the city¡¯s history and to expose the visitor to a rich architectural heritage. Downtown Seoul is rich in exclusive shops, galleries and museums. The bustling central city is ringed the fantastic natural setting of magnificent mountains and the spectacular Han River.
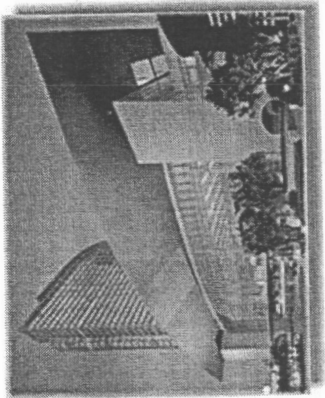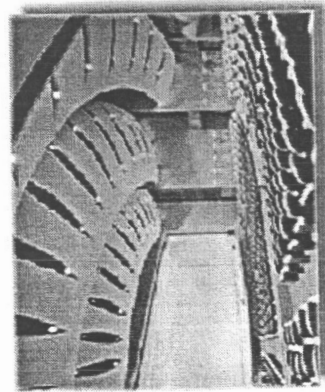
● Click here to see more about Seoul

● **Symposium venue**

Convention & Exhibition Center, Seoul, Korea

Exhibition
Prospectus2005

Student Prize
Paper Competition

(http://www.coex.co.kr/English/)
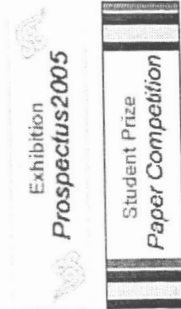
Located in the world trade center Seoul complex, COEX is a world class convention center offering a perfect infrastructure including deluxe hotels, shopping mall, recreation areas, cultural facilities, and transportation conveniences.

⊕ Click here to see more

● ¡°Incheon¡± airport

Built on an extensive reclaimed tidal land between two islands, Incheon International Airport is situated 52km east of downtown Seoul and some 15 km off the west coast of Incheon. It is open for 24 hours a day. The airport code of the Incheon International Airport (IIA) is ICN. Limousine buses may be the best way to trravel easily, at minimal expense, to and from various places around Korea. Information and tickets are available at the Transportation Information Desks near exits No. 2, 4, 9, and 13 on the arrival floor of the passenger terminal.
Transportation from the Incheon Internationa Aiport to the venue and hotel
Incheon International Airport web site - www.airport.co.kr

● Transportation in Seoul

⊕ Click here for information about the Incheon Int'l Airport (Korea's Premier airport) and transportation from the Incheon Int'l Airport to the COEX convention center.

● Weather

The peninsula is located mid-latitude in the northern hemisphere. It has four distinct seasons. The p;&nb;north-to-south geography of the peninsula produces climatic differences along its length. In the south, spring and summer are normally longer, while in the north, autumn and winter are longer.
Summer starts in June and continues to early September. Half of the annual rainfall drops during the Monsoon season of late June to early July. The average temperature of late July is 26.4 °C (79.52 °F).

● Foreign Exchange and Credit Cards

The unit of Korean currency is the won. Coin denominations are \10, \50, \100, \500. Bank notes are \1,000, \5,000, and \10,000. Bank checks are circulated in denominations of \100,000 and over. Foreign currency and traveler's checks can be converted into Korean won at foreign exchange banks and other authorized money changers.

The exchange rate is subject to market fluctuations. One U.S. dollar was equivalent to about 1,066 won as of Feburary 10, 2005. Credit cards, including VISA, American Express, Diner's Club, Master card and JCB, are accepted at major hotels, department stores, and larger restaurants.

Shopping

There are lots of good shopping places where you can enjoy and experience Korean shopping culture such as Wholesale Clothing Markets (Clothing Shopping Mall) , Traditional Markets, Department Stores

☺ Click here to see more

Business Hours

Public business hours are 9:00 to 17:00 Monday through Friday.

Electricity

In Korea, power outlets of 220 volts are dominant. Always check the power supply before using your equipment.

Emergencies

Dial 112 for the police and 119 for the fire and disaster department (though spoken in Korean). A hotel front desk or hotel manager can arrange for a doctor or an ambulance. If you need a doctor on the street, ask a policeman or passerby for assistance. Police boxes can be found on every major street. In addition, **International SOS Korea** (02-790-7561) provides a 24-hour emergency service for foreigners, acting as a link between patients and Korean hospitals with a charge.

Insurance and Liability

The Organizing Committee will not be responsible for medical expenses, accidents, losses or other unexpected damage to property belonging to symposium participants, either during or as a result of the symposium and during all tours and events. Participants are strongly advised to arrange their own insurance for health and accident, lost luggage and trip cancellation.

Formalities (about possession of a valid passport or identity card)

Foreigners wishing to enter the Republic of Korea should possess valid passports. Most visitors with confirmed round-tickets can stay for 15 days without visas, although this does not apply to certain nationalities. Meanwhile, any visitors from countries that have no diplomatic relations or no special visa exemption with Korea should obtain entry visa before

coming to Korea. When uncertain as to the requirements for entry visa to Korea, please contact the Korean Embassy or a consulate nearest in your area as early as possible. For more information, please visit the Ministry of Foreign Affairs and Trade at http://www.mofat.go.kr/en/index.mof

● Language

The official language of the Symposium is English.

● Contacts

IGARSS2005 Secretariat

Meci International Convention Services, Inc.

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E-mail

✑ **reg@igarss05.org : About registration information**

✑ **tour@igarss05.org : About tour information**

✑ **hotel@igarss05.org : About hotel information**

● Useful web sites about Korea

Seoul City web site - http://english.seoul.go.kr/

Korea National Tourism Organization(KNTO) web site - http://www.knto.or.kr/eng

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